C. F. BORGES, ASSOCIATE PROFESSOR OF MATHEMATICS

TOTAL LEAST SQUARES FITTING OF ORDERED DATA WITH POLYNOMIAL SPLINES

Sponsor: Unfunded

Objective: To develop fast and numerically stable algorithms for fitting polynomial splines to ordered data with minimal error in the total least-squares sense.

Summary: This unfunded effort is a continuing research project. The idea is to fit parametric polynomial spline curves to ordered data to get the best possible fit. Unlike traditional least-squares methods we assume that errors may occur in both the x and y directions. Moreover, we allow the data to be completely general - in particular, it does not have to be functional in nature, it may overlap itself or change directions without restriction. All that is required is an ordered set of points in the plane. I have investigated a variety of different approaches and have developed some very fast and robust algorithms for solving the problem for a single Bezier curve. I have also started work on extending this approach to multi-segment Bezier curves with arbitrary continuity conditions.

DOD Key Technology Area: Scientific Computation

Keywords: Curve Fitting, Data Compression, and Approximation Theory.

PUBLICATIONS
Carlos F. Borges, Associate Professor of Mathematics
January 2000 to December 2000

JOURNAL PAPERS

1. Middlebrook, E.E., Mansager, B.K., and Borges, C.F.*, A Brief Combat Simulation Analysis of Autonomous Legged Underwater Vehicles*, Military Operations Research, vol. 5, no. 1, January 2000, pp. 17-27.

W. GRAGG, PROFESSOR OF MATHEMATICS

Publications.

D. Calvetti, G.H. Golub, W.B. Gragg and L. Reichel, Computation of Gauss-Kronrod quadrature rules, Mathematics of Computation, Vol. 69 (2000) 1035-1052.

WEI KANG, ASSOCIATE PROFESSOR OF MATHEMATICS

Formation Control with Air Force Applications
SPONSOR: Air Force Research Lab
CO-SPONSOR: NPS

OBJECTIVE: The objectives of the project are 1. the development of theoretical basis for the formation control of multiple vehicles; 2. design controllers and STR projections for formations of spacecraft. 3. coordinated control of orientation and pointing of multi-satellite systems. 4. carry out simulations and experiments to test the formation control algorithm and the designed controllers.

SUMMARY: The PI visited AFRL on WPAFB for two weeks to collaborate with the AFRL research team in this subject. The design algorithm based on perceptive frame developed in NPS and MSU is combined with the sliding mode controller developed in AFRL. A joint paper with AFRL on satellite formation control is submitted to AIAA conference based on the collaboration.

Visible Sets and Its Manufacturing Applications
SPONSOR: Ford Scientific Research Lab
CO-SPONSOR: NPS

OBJECTIVE: The focus of this project for the year of 2000 is on the production planning based on information feedback. The objective is to develop mathematical model for production planning taking the advantage of today's high speed internet data transfer. The purpose of developing such model is to provide theoretical tools for analysis and automation for future B-to-B e-commerce in automotive and similar industries.

SUMMARY: Mathematical model of production planning integrating both statistical data and IT based fast information feedback is developed. A cost function is developed for dynamical production planning and adaptive optimization. Max-Plus algebra is used to model flexible production lines. The paper based on this project won the "Best Paper Award" in the 6th International Conference on Control, Automation, Robotics and Vision held in Singapore in December, 2000. The award is selected among about 360 papers published in the conference.

Coordinated Formation and Attitude Control of Multi-Satellite Systems
SPONSOR: Air Force Research Lab
CO-SPONSOR: NPS

OBJECTIVE: The objective of this project is to design a cooperative controller for the coordination of multiple satellites flying in formation. It includes the development of feedback for individual satellite, the coordination of multiple feedbacks, and coordination strategies for the relative attitude control of multiple satellites.

SUMMARY: Both sliding mode controller and H-infinity controller are developed for the attitude control of individual satellites. The proposed cooperative control is based on the perceptive frame. Some simulations show a significantly reduced overall tracking error. A conference paper and a journal paper are submitted as part of the product from this project.

PUBLICATIONS:

[1] W. Kang, Bifurcation control via state feedback for systems with a single uncontrollable mode, *SIAM J. Control and Optimization*, 38, (2000), 1428-1452.

[2] W. Kang, A. Sparks, S. Banda, Coordinated Control of Multi-Satellite Systems, *AIAA J. of Guidance, Control, \& Dynamics,* to appear.

[3] I. Kaminer, A. M. Pascoal, W. Kang, O. Yakimenko, Integrated Vision/Inertial Navigation Systems Design Using Nonlinear Filtering, *IEEE Trans on Aerospace and Electronics*, to appear.

[4] W. Kang and F. A. Papoulias, Bifurcation and Control of Submersible Vehicles with Dive Plane Reversal, *Latin American Applied Research-An International Journal*, to appear.

[5] W. Kang, A. Sparks, S. Banda, Multi-satellite formation and reconfiguration, Proc. American Control Conference, Chicago, Illinois, June 28-30, 2000.

[6] W. Kang, N Xi, A. Sparks, Formation Control of Autonomous Agents in 3D Workspace, Proc. IEEE International Conference on Robotics and Automation, San Francisco, California, April 24-28, 2000.

[7] W. Kang, M. Song, Manufacturing planning based on information feedback, Proc. 6th International Conference on Control, Automation, Robotics and Vision, Singapore, December 5-8, 2000.

[8] D. E. Chang, W. Kang, and A. J. Krener, Normal Forms and Bifurcations of Control Systems, Proc. IEEE Conference on Decision and Control, Sydney, Australia, December 12-15, 2000.

[9]B. Hamzi, W. Kang, and J-P. Barbot, On the Control of Hopf Bifurcations, Proc. IEEE Conference on Decision and Control, Sydney, Australia, December 12-15, 2000.

[10] M. Xiao and W. Kang, Bifurcation Control Uising Integral Averaging Method, Proc. IEEE Conference on Decision and Control, Sydney, Australia, December 12-15, 2000.

[11] W. Kang, N. Xi and A. Sparks, Theory and Applications of Formation Control in a Perceptive Referenced Frame, Proc. IEEE Conference on Decision and Control, Sydney, Australia, December 12-15, 2000.

B. NETA, PROFESSOR OF MATHEMATICS

ATTITUDE DETERMINATION

Sponsor: unfunded

SUMMARY:
Various k-vector range searching techniques are presented. These methods accomplish the range search by taking advantage of an n-long vector of integers, called the k-vector, to minimize the search time. The price is increased memory requirement for the k-vector allocation. However, it is possible to balance the extra memory required and the speed attained by choosing a step parameter h, which samples the k-vector. A two-level k-vector technique is also presented to minimize the speed of the admissible data identification associated with a given range. The proposed methods are compared with the well-known ``binary search" technique, and demonstrate a high-speed gain rate (from 9 to more than 40 times). Finally, just to show one of the wide-range possible applications, a method to compute the *arcsin* function, based on the k-vector technique and a look-up table, is presented

Keywords:
Attitude determination, search algorithms.

DoD Key Technology Areas:
Computing and Software, Space Vehicles, Modeling and Simulation

PUBLICATIONS

1. C. A. Kluever, B. Neta, C. D. Hall, and J. M. Hanson, Spaceflight Mechanics 2000, Advances in the Astronautical Sciences, Vol. 105, Univelt, Inc., San Diego, 2000. Two volume book.

2. D. Mortari, and B. Neta, k-vector range searching techniques, Proc. *AAS/AIAA Space Flight Mechanics Meeting*, Clearwater, FL, January 23-26, 2000, Paper Number AAS 00-128.

PRESENTATIONS

3. AAS/AIAA Space Flight Mechanics Meeting, Clearwater, FL, January 23-26, 2000, *k-vector range searching techniques*

GPS Trajectory Averaging

Sponsor: National Imagery and Mapping Agency, Systems Center and NPS

SUMMARY:
Numerous independent sets of data have been taken obtained. The steps in carrying out the required tasks are: partition sets of data into pieces that correspond to a particular part of a roadway and that have been taken using a single satellite configuration, select a portion of that path to be fit by a straight line or by a parametric cubic curve with continuous tangent vector, and compare the curves obtained for independent sets of data over the same path to estimate the bias vector between the two. When these steps are performed for many independent tracks an estimate of the true bias can be obtained. Matlab programs have been written that perform each of the above tasks.

Keywords:
GPS, Bezier, Matlab.

DoD Key Technology Areas:
Computing and Software, Modeling and Simulation

PUBLICATIONS

1. J. R. Clynch, R. Franke and B. Neta, Improvements In Dynamic GPS Positions Using Track Averaging, Proc. ION Tech. Meeting, January 26-28, 2000, Anaheim, CA.

PRESENTATIONS

1. ION Tech. Meeting, January 26-28, 2000, Anaheim, CA,
Improvements In Dynamic GPS Positions Using Track Averaging

Efficient Nonlinear Transient Dynamic Analysis for Structural Optimization Using an Exact Integral Equation Formulation

Sponsor: National Science Foundation

SUMMARY: The focus of this phase of the project is the development of an improved solution algorithm for fast transient analysis of large, locally nonlinear structures using time domain structural synthesis. Time domain structural synthesis is a general and exact formulation for transient problems in structural modification, substructure coupling, and base excitation. The formulation is characterized by the governing equation of the synthesis, which is a nonlinear Volterra integral equation. The governing equation makes use of impulse response functions calculated for those coordinates of the (sub)structures subjected to forces of synthesis (e.g. modification forces, coupling forces). This physical coordinate formulation provides for a largely unrestricted and exact model reduction, in that only those coordinates of interest need be retained in the synthesis. We document the development of several algorithms intended to improve upon the original algorithm developed by Gordis. The last algorithm developed meets the stated goals of the project. This algorithm is a newly developed recursive, block-by-block convolution solution to the governing nonlinear integral equation. As is demonstrated with a simple but realistically large nonlinear base excitation problem (51,500 DOF finite element model), the new algorithm provides a 78\% reduction in time required for the nonlinear transient base excitation solution, as compared with traditional direct integration calculated using a widely-used commercial finite element program. This very large savings in computer time is obtained for a single analysis, i.e. assuming no prior calculations have been made for the impulse response functions of the (sub)structures. The new algorithm provides an even greater reduction in computer time for all subsequent analyses. As shown in the example problem, once all required impulse response functions have been calculated, the nonlinear base isolation solutions calculated using the new recursive, block-by-block convolution algorithm take approximately 7 seconds, as compared with the direct integration solution which takes approximately 30 minutes. This rapid reanalysis capability will facilitate the development of numerical optimization for the design of nonlinear isolation.

Keywords:
finite elements, structural synthesis, convolution, block-by-block, adaptive

DoD Key Technology Areas:
Computing and Software, Modeling and Simulation

PUBLICATIONS

1. J. Gordis and B. Neta, An adaptive method for the numerical solution of Volterra integral equations, *Recent Advances in Applied and Theoretical Mathematics*, N. Mastorakis, editor, World Scientific and Engineering Society International Conference, Athens, Greece, December 1-3, 2000, pp. 1-8.

2. J. Gordis and B. Neta, An adaptive method for the numerical solution of Volterra integral equations*, Recent Advances in Applied and Theoretical Mathematics*, N. Mastorakis, editor, World Scientific and Engineering Society International Conference, Athens, Greece, December 1-3, 2000, pp. 1-8.

3. J. H. Gordis, and B. Neta, Fast transient analysis for locally nonlinear structures by recursive block convolution, ASME J. Vibrations and Acoustics, submitted for publication.

PRESENTATIONS

4. World Scientific and Engineering Society International Conference, Athens, Greece, December 1-3, 2000,
An adaptive method for the numerical solution of Volterra integral equations

ORBIT DETERMINATION

Sponsor: unfunded

SUMMARY:
Super implicit and Obrechkoff high order methods were compared for the solution of first and second order initial value problem. The second order problems of interest are those not containing first derivatives.

Keywords:
Orbit determination, Initial value problems.

DoD Key Technology Areas:
Computing and Software, Modeling and Simulation

PUBLICATIONS

1. B. Neta and T. Fukushima, Obrechkoff versus super-implicit methods for the solution of first and second order initial value problems, Computers and Mathematics with Applications, special issue on Numerical Methods in Physics, Chemistry and Engineering, T. E. Simos and G. Abdelas (guest editors), accepted for publication.

2. B. Neta and T. Fukushima, Obrechkoff versus super-implicit methods for the integration of Keplerian orbits, *Proc. AIAA/AAS Astrodynamics Specialist Conference*, Denver, CO, August 14-17, 2000, Paper Number AIAA 2000-4029.

PRESENTATIONS

3. AIAA/AAS Astrodynamics Specialist Conference, Denver, CO, August 14-17, 2000, *Obrechkoff versus super-implicit methods for the integration of Keplerian orbits*